A LIMNOLOGICAL STUDY OF AN OHIO FARM POND

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The interactions of organisms and their environment must be considered when establishing a sound fish management program. Reports on the development of new fish management practices for farm ponds have not in general been accompanied by the biological, chemical, and physical data upon which such practices were developed.

Limnological studies, even for ponds other than farm ponds, are few in number. Wiebe (1929, 1930, 1934) and Surber and Olson (1936) published data on the biological and chemical conditions existing in hatchery ponds. Their papers are among the few that contain detailed data on selected conditions in such ponds. In the literature there are a few studies on the biological, chemical, and physical conditions of "farm" ponds. Fritsch and Rich (1909, 1913) conducted a four year study on one pond and a five-year study on another in the British Isles; Whitney (1942) studied diurnal fluctuations of oxygen and pH in two small ponds in the British Isles; Laurie (1942) investigated the fauna of an upland pond in Wales; Ward (1940) studied selected chemical conditions and the Entomostraca of a "sheep" pond in Ohio; and Greenbank (1945) studied several winter chemical conditions of an "artificial" pond in Michigan.

The study presented here is an attempt to describe and analyze selected biological, chemical, and physical data for 16 months from a farm pond near Columbus, Ohio. No attempt was made to manage this pond or to solve any problems of farm pond management; the study was initiated to investigate some conditions existing in a specific pond with the immediate purpose of exposing problems for future study. The results of this study indicate that such problems are related to: (1) The influence of an algal surface cover on some physical, chemical, and biological conditions. (2) The dominance of zooplankters, especially rotifers, in the net plankton. (3) The reappearance of similar genera and physical and chemical conditions in successive years. (4) Daily and seasonal variability in biological, chemical, and physical conditions.

LOCATION AND DESCRIPTION OF FARM POND

The pond is located in Franklin County, Ohio, on the Ohio State University Farm. At high water it is approximately one-half acre in area; a dam extends approximately north and south and the pond proper extends westerly from this dam. During the period of study the greatest maximum depth was approximately seven feet and the lowest maximum about five feet (fig. 1).

The watershed is of soils of the Miami Catena, consisting of Brookston silty clay loam, Celina silt loam, Crosby silt loam, and Miami silt loam; it is predominately of Celina silt loam and Miami silt loam. The watershed has a slope of 2 to 5 percent with slight-to-moderate sheet erosion. During the study, the watershed, exclusive of a woodlot located to the southwest of the pond, was covered with alternating fields of corn and alfalfa transected by sodded waterways. So far as can be determined, water drainage into the pond is primarily from the farmed area. The position of a small tile at the bottom of the pond indicates drainage from a small woodlot, on Crosby silt loam, to the southwest.

Initial construction of the pond was completed by August 25, 1944. As a result of water seepage, a state of repair existed until the summer of 1946. Five

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tons of No. 200 Bentonite were used to prevent seepage after drainage tile were removed from the pond. From the completion of excavation until the fall of 1946, when fish were stocked, the pond was twice filled with water.

METHODS

General

The net plankton and algal mat, as well as selected chemical and physical conditions, were studied at weekly intervals for 16 months and some studies on a daily basis. From initiation of the study on April 2, 1948, until June 21, 1949, no attempts were made to disturb the pond in any way. On June 22, 1949, a study was initiated to determine the effect of the removal of the algal mat on selected

FIGURE 1. Farm pond at low water, November 4, 1948.

biological, physical, and chemical conditions. When collecting net plankton and water samples, the air temperature, wind direction, wind velocity, sky condition, occurence of precipitation, and the pond surface condition were recorded.

Hydrogen-ion concentration, vertical plankton distribution, bottom organisms, and various chemical constituents of the water were not studied.

Biological

Net plankton. Net plankton were collected by pouring 90 liters of pond water through a No. 20 bolting silk plankton net. Transeau's preservative (6 parts distilled water, 3 parts of 95 percent ethyl alcohol, 1 part formalin) was added to the concentrated sample from the net until a volume of 45 cc was obtained. Plankton and water samples were collected in the vicinity of the overflow. Plankton were collected from a restricted area only during periods of ice cover and when the algal mat encroached on the "overflow area." For example, periods of algal mat encroachment occurred during July 1948; the open area adjacent to the platform was estimated as 36 square feet on the first of the month; 16 square feet on the 8th; less than 16 square feet on the 15th; 28 square feet on the 22nd; and more than 120 square feet on the 29th. At such times the algal mat covered almost completely the entire pond surface.

A special plankton "collection shelter" for use during winter was placed in the overflow and used during most of the study. A small kerosene brooder stove was used in the shelter during winter to prevent freezing of the plankton net.

Differential counts of net plankton were made in a No. 800 Sedgewick-Rafter counting chamber. Using a 1 cc pipette with an enlarged opening, 1 cc of the concentrate was placed in the counting chamber. Twenty-four evenly spaced cubic millimeters, 8 in each of three parallel rows, were counted through a 16-millimeter objective and a 10x ocular. Ten 1 cc portions were counted so that an average value might be obtained. Replications were undertaken in the event that the significance of the difference between the average values obtained during different sampling periods might be arrived at by statistical means. The 24 cubic millimeters counted were not selected at random since, according to the investigations of Littleford, *et al.* (1940), there is no apparent advantage in a random selection. They state, "It has been found that counts based upon the selection of groups of areas at random are about the same as those obtained according to selection."

In general, organisms have been identified to genera. The difficulty of identifying preserved ciliates, unless identification of a certain genus was thought reliable, resulted in their being classed as one group (ciliates). Filamentous forms common to the algal mat occurred rarely in the counts and were not tabulated. Because of difficulty in identifying fragments of certain filamentous Myxophyceans all such forms were classified as *Oscillatoria*. An example of such a form is *Lyngbya*, the only filamentous Myxophycean similar to *Oscillatoria* that was identified. All filamentous forms tabulated were recorded as one individual, irrespective of length. *Synedra* and *Navicula* were tabulated as naviculoid forms.

As a result of difficulty in separating preserved Bdelloids from small contracted "sac-like" rotifers, such as *Synchaeta*, these forms were all tabulated as "sac" rotifers. The relative abundance of these two groups, as determined by observing samples containing living organisms, is discussed later. With the exception of "spinous processes," organisms were counted as complete, irrespective of the amount of the organism appearing within the one cubic millimeter counted. Organisms believed dead prior to preservation were tabulated; for example, diatoms as frustules; Entomostraca and Rotifera as dead metazoans. All forms, whether "dead or alive," "complete" organisms, or eggs, were tabulated in the total count.

Algal mat. Samples from various areas of the algal mat were collected and the organisms present were tabulated as to relative abundance.

The errors and precautions involved in the methods employed in sampling, identifying, counting, and tabulating are for the most part obvious and have been discussed adequately elsewhere (Littleford, *et al.*, 1940; Welch, 1948; Ricker, 1932; Allen, 1930; Taft, 1949; Lackey, 1939).

Physical and Chemical

Physical. General physical conditions existing at the time of sampling were recorded in relative terms. Air temperatures, taken in the shade, and water temperatures were determined with a mercury thermometer. Temperatures were estimated to 0.25° C.

A Secchi disk, 6 inches in diameter, was used to estimate the extent of light penentration. Sky conditions were recorded as clear, partly cloudy, or overcast.

Wind conditions were recorded as calm, slight, or heavy. The wind direction was estimated to the nearest half quadrant.

"Open water" surface conditions in the area of sampling were classed as calm, slight ripples, or heavy ripples. Due to the location of the pond in relation to the small woodlot and surrounding topography, winds of similar velocities from different directions did not have the same effect upon the surface of the sampling area. Those from the southwest, west, and northwest appeared to have the greatest effect on the surface where sampling occurred. Precipitation was recorded as absent or present during the time of sampling.

Weather conditions during the week prior to sampling probably had a major effect on the pond. Therefore, the maximum and minimum temperatures and precipitation as recorded at The Ohio State University Weather Station were studied. Although this station is approximately one mile from the pond, these data probably present a general picture of conditions that existed there.

The time of sunrise and sunset, as well as the time of collection, was recorded so that the effects of photosynthesis might be fully evaluated. It is believed that the hour of collection, often not recorded in limnological papers of this type, is an essential for complete data.

Chemical. Water samples were collected with a Foerst water sampler (12 inch cylinder). Samples were taken at the surface (refers to open water, i.e., no algal mat present), at the bottom and in the algal mat. Water in the algal mat was obtained merely by making a small hole in the mat and inserting the sampler just below the surface. Samples were also collected in open water areas in the mat and in portions of the mat on the bottom of the pond. Chemical determinations were started within 15 minutes after collecting the last sample. All samples were collected within 5 minutes of the time designated on the data sheets.

The dissolved oxygen content was determined by the Rideal-Stewart modification of the Winkler method (American Public Health Association, 1946). A starch solution (after Ellis, *et al.* 1946) was used as an indicator and correction was made for the addition of reagents. Oxygen saturation values were determined, when possible, by means of a nomogram from Rawson (1944) and others calculated from the tables of Whipple and Whipple (American Public Health Association, 1946). Saturation values were calculated to the normal pressure of the region.

Free carbon dioxide, hydroxide (OH^-), normal carbonate ($CO_3^=$), and bicarbonate (HCO_3^-), were determined according to Ellis, *et al.* (1946). A 250 cc Erlenmeyer flask was used in place of a Nessler tube for the determination of free carbon dioxide. Xylene cyanole-methyl orange indicator was substituted for methyl orange indicator on June 18, 1948, and used until completion of the study.

Indicators (except the starch solution) and standard solutions necessary for all determinations were obtained from the Control and Reagent Laboratory of The Ohio State University.

DISCUSSION OF OBSERVATIONS

Physical and Chemical

Physical. Air temperature at the time of sampling showed great variability throughout the period of study. A low of $-4.5°$ C was observed January 20, 1949; a high of 35.0° C occurred July 15 and July 22, 1948, and a high of 38.25° C on June 24, 1949. Comparison of these data with those of the university weather station indicates greater extremes in temperature occur at the pond than at the station.

From the latter part of March until the second week of September the temperature of the surface water exceeded that at the bottom. During the remainder of the year, with few exceptions, the surface temperature was lower than at the bottom. The temperature of the water in or under the floating algal mat during the summer period generally was intermediate between that of the open surface and bottom. During autumn the water temperature in the algal mat generally equaled or exceeded that of the open surface water (fig. 2).

Comparisons of the temperature of pre- and post-noon water samples (fig. 3) indicate that the temperature of the surface and bottom increases with a rise in air temperature, the change at the surface being more extreme than at the bottom. Rainfall during the summer months was followed by a decrease in temperature of the surface water.

As to the temperature of ponds in midwestern United States, Anderson (1948) remarks: " . . . bluegills do not spawn until the water temperature has reached 80° F. (26.7° C), usually about July 1 in this region . . . ." It is true that temperature values as high as 26.7° C were not recorded at the surface, bottom, or in the algal mat until July in the pond studied, but bluegills were observed spawning during May in about three feet of water, when the surface temperature was 22.0° C and the bottom (depth of 67") 21.0° C.

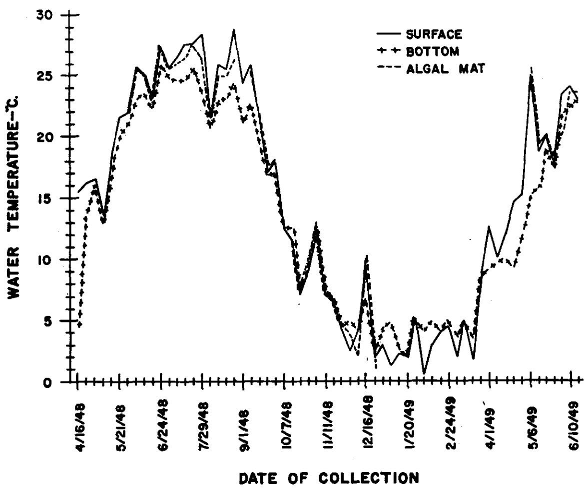

FIGURE 2. Water temperature at time of sampling.

Secchi disk readings taken throughout the year indicated that maximum light transmission in open water occurred concurrently with the presence of an algal mat through the summer and into the late fall. During this period the bottom of the pond was visible. Fessler (1949) also observed that water in heavily vegetated ponds was clear. With the subsequent removal of the algal mat and agitation of bottom materials on June 22, 1949, the bottom was, with one exception, not visible for the remainder of the pond's "existence" (August 30, 1949). Except for a reading on April 16, 1948, minimum Secchi disk readings were obtained during February and the latter part of January.

At the initiation of the study on April 2, 1948, water was pouring into the overflow, but as summer progressed the water level decreased and remained low until late December (fig. 1). Rainfall throughout the summer and fall had little effect on the water level. Comparison of the water level in an evaporation pit (without an algal mat) adjacent to the pond and that in the pond (with an algal mat) indicated that the mat enormously increased the amount of evaporation from the pond. A relatively high water level and the absence of an algal occurred during the summer of 1947.

Chemical. The amount of dissolved oxygen varied extremely (fig. 4). This was probably a result of photosynthesis by algae and a direct result of physical factors such as precipitation and strong winds. Presence of certain plants has been shown to be associated with daily variation in the dissolved oxygen content of water (Wiebe, 1934; Whitney, 1942; Laurie, 1942; Roach and Wickliff, 1934). The dissolved oxygen data obtained late in the spring of 1948 differed radically from those in late spring of 1949; during 1948, the dissolved oxygen content was

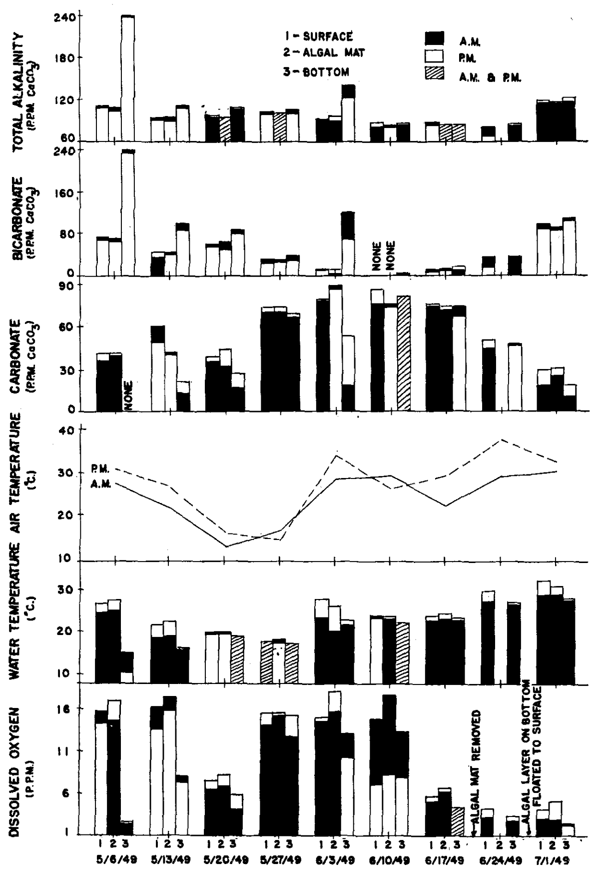

FIGURE 3. Pre- and post-noon physical and chemical determinations.

generally higher at the bottom than the surface. This relationship was reversed concurrently with the rise of filamentous algae to the surface during the week prior to June 24. A limited amount of filamentous algae was present prior to June 24 along the edges and at places extended out a few feet from the margin of the pond. From June 24, 1948, until termination of the study, with few exceptions the dissolved oxygen content at the surface exceeded or equaled that at the bottom. The lack of repetition of similar bottom and surface oxygen relationships in 1949 probably resulted from a period of high air temperature during which an extensive algal mat appeared on the surface during the week prior to May 6, 1949. Results of analyses on June 4, 10, 21, and 29 (fig. 5, 6), substantiate these inferences regarding conditions during late spring of 1948. The decrease in dissolved oxygen throughout the day of June 10, 1948, in the algal mat, may have been the result of heavy winds.

In general, the lowest dissolved oxygen in the algal mat occurred during late summer and early fall.

According to Moore (1942), "Although more data would be desirable one seems justified in concluding that an oxygen content of at least 3.5 ppm is essential to the maintence of fish life at summer temperature." Only three records of less than 3.5 ppm of dissolved oxygen were found in the present study and these were on bottom samples. Concurrently with a low of 0.1 ppm of dissolved oxygen at the bottom on July 29, 1948, fish were observed at the surface for the first time during midday.

Analysis of data obtained during a 24 hour period on June 4 and 5 (fig. 5), prior to the uplift of filamentous algae from the bottom, poses some interesting problems. Data from water in the floating algae along the shore showed an increase in dissolved oxygen during the hours around midnight, concurrent with a

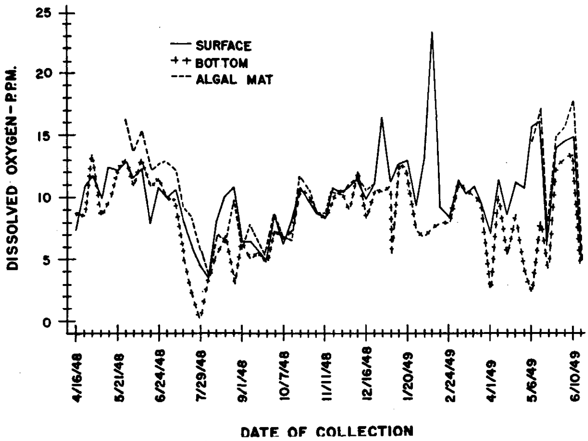

FIGURE 4. Dissolved oxygen values.

decrease of dissolved oxygen in water in the submerged filamentous algae (submerged about two feet); a possible explanation is the movement of oxygen from water in submerged algae to the surface. The reason for an increase in oxygen at the bottom from 4 P.M. until midnight is unknown. The amount of dissolved oxygen in the surface remained fairly constant throughout the afternoon and night. During the period from 4 A.M. to 6 A.M. on June 4, 1948 there was a decrease in the dissolved oxygen in all areas sampled. The decrease was rapid at the surface and slow in the floating algal mat.

Peaks of dissolved oxygen (fig. 4) on December 30, 1948 and February 10, 1949 were accompanied by the largest numbers of phytoplankton, predominately *Chlamydomonas*, observed during the study. A unique feature, on February 2, was a dark green layer of *Chlamydomonas*, about one inch thick, at a depth greater than the Secchi disk reading (about 24 inches). An ice cover ⅜ inch thick existed and the water appeared to be in an unstable condition because it "turned over" at the slightest agitation. The temperature of surface water was recorded as 3° C; silt was present on the lower surface of the ice. The raising of the disk resulted in the observation of this green layer as currents lifted it to the surface. An attempt was made to obtain a sample of this band with a jar as the layer rose to the surface. A count of 1 cc of this sample resulted in a value of 8,456,250

Chlamydomonas per liter. The mixture of the desired sample with "clear" water indicates that the true value was greatly in excess of this value. A somewhat similar condition in which a sudden mortality of fishes was accompanied by a supersaturation of oxygen and a bloom, principally of *Chlamydomonas*, was reported by Woodbury (1941) in a Wisconsin lake during April.

The amount of dissolved oxygen in the algal mat exceeded that both at the bottom and surface; this condition existed for an extensive period until August,

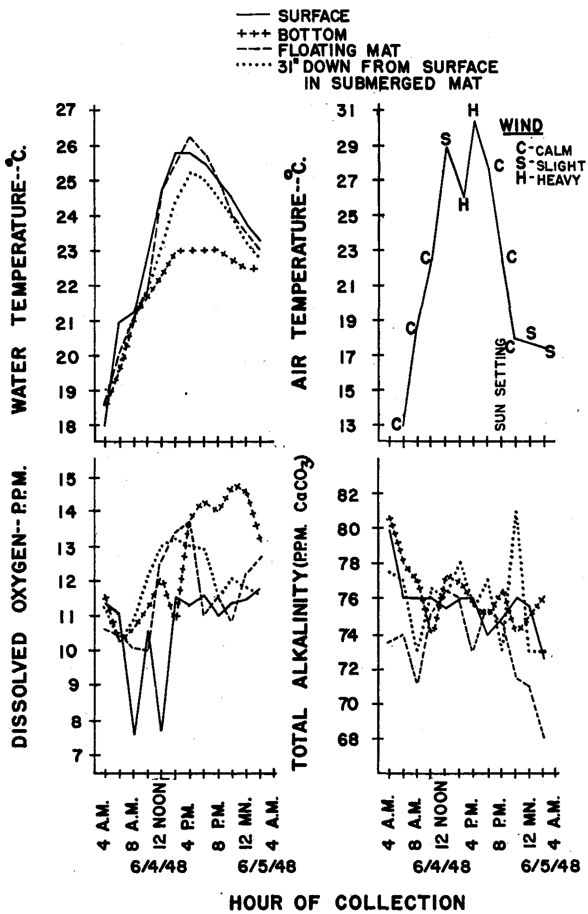

FIGURE 5. Physical and chemical values during a 24 hour period.

after which values greater, less or equal to those of the bottom and surface were found. The simultaneous occurrence of similar physical and chemical conditions of the three sampling areas (surface, bottom, and algal mat) indicates that the fall overturn occurred around September 23, 1949.

Oxygen saturation values during successive samplings were variable (fig. 7); the greatest generally being during spring and early summer. The contours of plotted values for oxygen saturation and dissolved oxygen in the three locations were very similar (fig. 4, 7). Supersaturation values were the rule rather than the exception in spring and early summer. Only six supersaturation values were obtained in the period from August 12, 1948 to April 1, 1949; four of these were in August and two during the "bloom" of *Chlamydomonas* in December and February. Reports of super-saturation values of dissolved oxygen in relation to green plants are common in the literature (Wiebe, 1934; Laurie, 1942; Moore, 1942; Birge and Juday, 1911; Woodbury, 1941; Smith, 1934).

The absence of free carbon dioxide from April 23 to July 15, 1948, coincided with a period of high dissolved oxygen. Free carbon dioxide was detected on April 16, 1948 at the surface and bottom. No determinations were made on samples from the limited algal mat on this date. Free carbon dioxide was not detected in any sample from April 17 through July 21, 1948. It was detected from

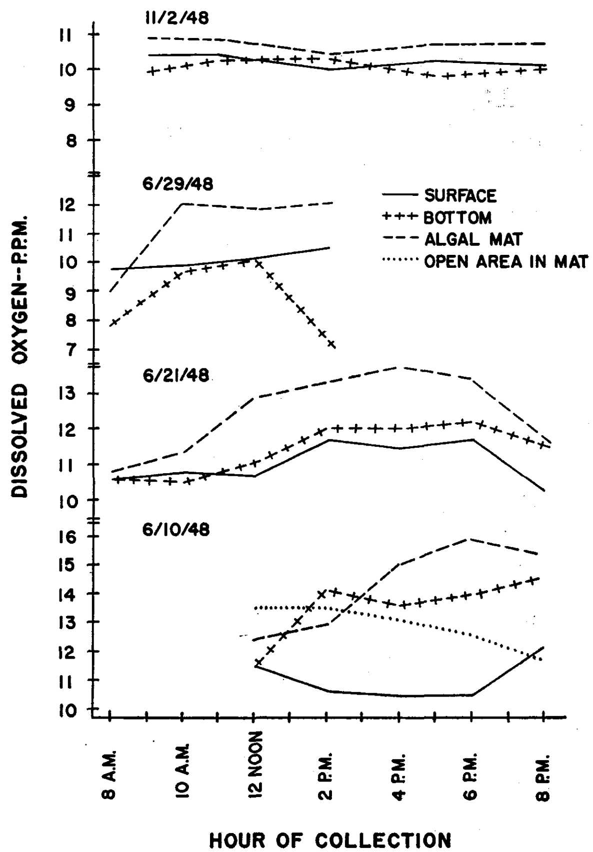

FIGURE 6. Daily dissolved oxygen values illustrating possible influences of algal mat.

July 22, 1948, to August 12, 1948 on the bottom; July 29, 1948 to August 5, 1948 on the surface; and only on August 5, 1948 in the algal mat. These periods were accompanied by relatively low dissolved oxygen values. Except for one record at the bottom on August 26, free carbon dioxide was not detected again until September 28, 1948, at which time it occurred simultaneously in the three sampling areas. It was detected, with four exceptions, until spring at the surface and bottom and in the remains of the algal mat until cessation of sampling on December 30, 1948. The exceptions were simultaneous with peaks of dissolved oxygen. The most notable exception was in the surface water on February 10, 1949, when the algal bloom was observed.

Free carbon dioxide values for the algal mat and surface water samples have similar distributions indicating either that similar conditions existed in the two areas or one or both of the areas were exerting a dominant influence on the free carbon dioxide level of the two areas. The longest period of occurrence and the greatest amount of free carbon dioxide was detected at the bottom.

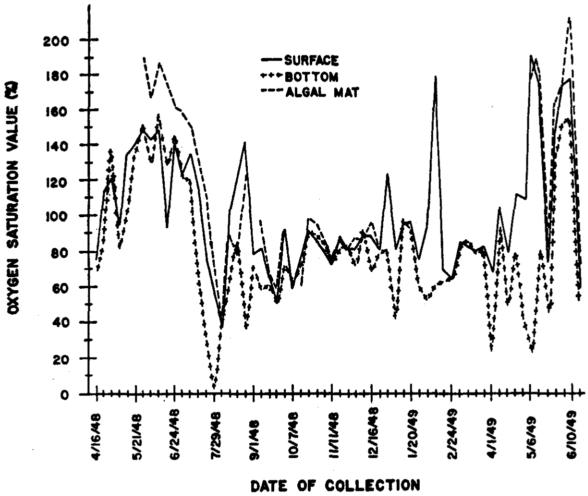

FIGURE 7. Oxygen saturation values.

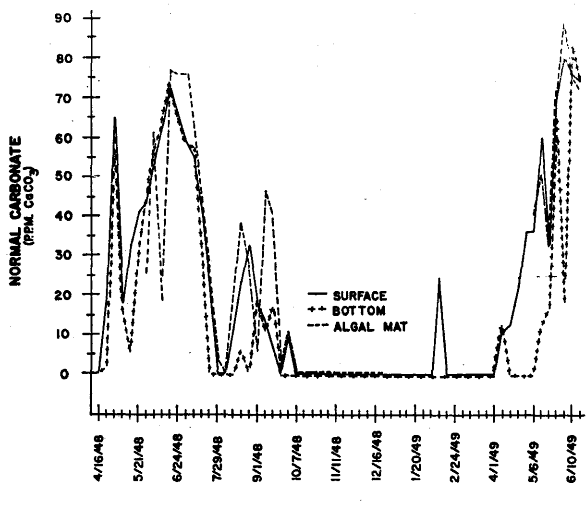

FIGURE 8. Normal carbonate values.

According to Lagler (1949), free carbon dioxide in excess of 20 ppm can be considered harmful to fish; values of less than this may be harmful if low oxygen values exist (less than 3 to 5 ppm). Only rarely did such a combination exist during the present study.

As expected, normal carbonate ($CO_3^{=}$) was detected only during the absence of free carbon dioxide. It was present primarily during spring, summer, and early autumn with a peak from late spring to mid-summer (fig. 8). During the winter months carbonate was detected only during the algal bloom on February 10, 1949. In general when an algal mat is present, there appears to be an increase in the normal carbonate and a decrease in the bicarbonate content between 10 A.M. and 2 P.M. A tendency for a decrease in bicarbonate during this period is probably

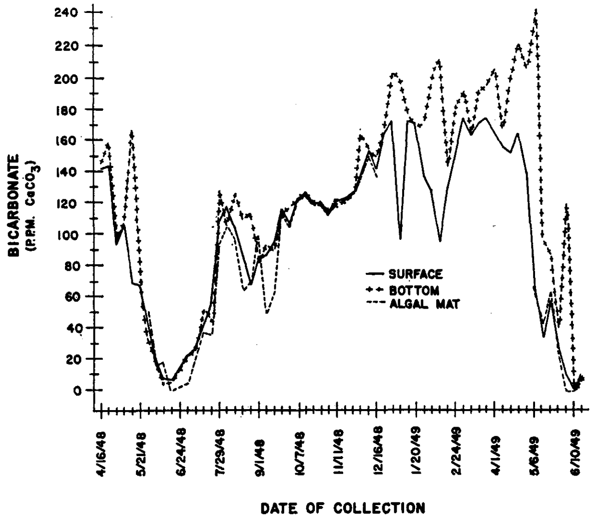

FIGURE 9. Bicarbonate values.

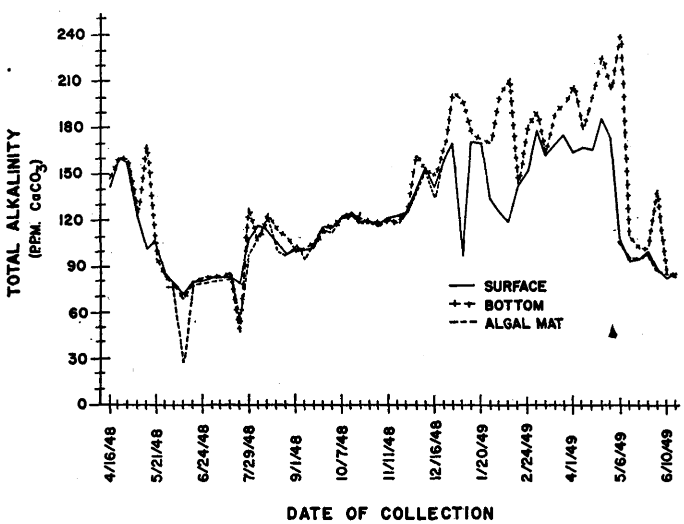

FIGURE 10. Total alkalinity values.

the result of photosynthesis. According to Chambers (1912), in the absence of free carbon dioxide plants use bicarbonates in the photosynthetic process. This is also reported by Smith (1934).

The process may be so vigorous that the bicarbonate is exhausted and the water becomes alkaline (Chambers, 1912). Fritsch, (1931) elaborates this statement:

"So marked a change towards the alkaline side results not only from the conversion of bicarbonate to carbonates but also from a withdrawal of CO_2 from the latter with the production of the hydroxide." Such a relationship existed in the algal mat on June 11, 1948 when the bicarbonate value was zero; the normal carbonate reached a value of 18.3 ppm and 9.1 ppm of hydroxide ($OH^=$) were detected.

Bicarbonate was greatest during winter and spring with lowest values occurring during the latter part of May and June (fig. 9). A relatively small amount of bicarbonate was present during the major algal bloom on February 10, 1949 and also one week following an algal bloom on December 30, 1948.

Total alkalinity was greatest during spring and winter (fig. 10). During this period the total alkalinity at the bottom equaled or exceeded that at the surface. During the summer, in the three areas sampled, the lowest total alkalinity generally occurred in the algal mat.

The various relationships between dissolved oxygen, free carbon dioxide, normal carbonate, and bicarbonate, daily and seasonally, offers fairly substantial evidence that the process of photosynthesis was exerting a strong influence on various factors in the pond.

Biological

Net plankton. Results of net plankton counts show that zooplankters were dominant during the spring. During the summer, at different periods, zooplankters or phytoplankters were dominant. Phytoplankters were dominant during winter; in general, they were present concurrently with the presence of free carbon dioxide and a minimum or absence of the algal mat. Diatoms were most abundant during spring. *Cyclotella*, *Gomphonema*, naviculoid forms, *Dinobryon*, and *Mallomonas* appeared to be predominantly spring forms, while *Cosmarium*, *Euglena*, *Pandorina*, *Scenedesmis*, and *Tracholomonas* occurred predominantly during the summer. *Cryptoglena* and *Cryptomonas* occurred during late fall, winter, spring, and early summer. *Chlamydomonas* was observed only during the winter. *Dinobryon* was observed only during the spring of 1948.

According to Hutchinson (1944), *Dinobryon* "appears to increase after the major components of the spring maximum have declined." The separation of *Characium* and *Cryptoglena* in the counting cell was difficult; therefore, when occurring together the numbers counted of these two forms are not accurate.

Zooplankters occurring in greatest numbers were generally rotifers, but during certain periods the Cladocera were dominant. Rotifers included *Anuraea*, *Asplanchna*, *Cathypna*, *Monostyla*, *Noteus*, *Pedalion*, *Philodina*, *Polyarthra*, *Rattulus*, *Schizocerca*, *Synchaeta*, and a few unidentified forms. Rotifers occurred in largest numbers during spring, summer, and fall. *Anuraea* was observed predominantly in spring, summer, and fall; *Asplanchna*, during summer; *Cathypna* and *Monostyla*, during spring and summer; *Polyarthra*, during spring; *Philodina roseola*, during winter; and *Synchaeta*, during winter and spring. *Monostyla* occurred more frequently and in greater numbers than did *Cathypna*. *Pedalion* and *Schizocerca* were observed in large numbers during August, 1949, a period following removal of the algal mat.

The Cladocera observed appear to be spring and early summer forms. *Chydorus* was less restricted in seasonal appearance than *Ceriodaphnia*, *Scapholeberis*, or *Simocephalus*. Of these latter three, *Simocephalus* was the first to appear in spring. It was observed in enormous numbers adjacent to the algal mat but was relatively rare in open water. Five adult bluegills examined had fed heavily upon this form. *Ceriodaphnia* and *Scapholeberis* were observed in large numbers only in open water. Many individual *Ceriodaphnia* were covered with Characium; this was observed during 1948 and 1949. In 1949, *Characium* occurred also on *Trachollomonas* (one observation), *Cyclops*, nauplii, and rotifers.

Net plankton samples collected during various hours of the day showed great varibility. The results of a twenty-four hour study on June 4, 1948 indicate that an increase in zooplankton at the surface occurs during the latter part of the day. An interesting observation was made on June 10, 1949 when at 10:30 A.M. great numbers of *Scapholeberis* were observed with winter eggs; at 2:30 P.M. no ephippia were observed and the majority of individuals contained parthenogenetic eggs.

With the exception of winter blooms of *Chlamydomonas*, the total number of net plankton was greatest during spring. Far greater numbers of organisms were observed during the spring of 1949 than in the spring of 1948, possibly resulting from manure being placed on the watershed during the winter months or from decomposition of the algal mat during the winter of 1948–49, or both. It is known that no extensive algal mat was present during the late summer and fall of 1947. Whether or not manure was placed on the watershed during the winter of 1947–48 is unknown.

Algal mat. The algal mat which apparently had an influence upon various conditions existing in the pond, possessed great seasonal variability in its composition. Algal samples collected on the upper and lower surfaces of the mat, in shallow water and in deep water, varied in species composition. Exclusive of scarce fragments of the algal mat of the "preceding" year, the first Chlorophyceans appeared in the inlet ditch; they consisted of, in order of occurrence, *Vaucheria, Ulothrix, Mougeotia* and *Stigioclonium.* These forms disappeared with the warming and disappearance of water in the ditch. *Oscillatoria* was observed prior to the above forms and was present in the pond during the greater part of year. It occurred in greatest numbers in the net plankton during the spring and fall overturns. In the pond proper *Cladophora* was the dominant spring form, but with the advent of warmer temperatures, *Oedogonium* became dominant. On the basis of cell size and form at least two species of *Oedogonium* were present. During the spring of 1948 a mass of pure Cladophora up to four feet thick was present under a surface layer of *Oedogonium.* This relationship was not observed during the spring of 1949, probably as a result of the early rise, in deep and in shallow water, of filamentous algae (primarilly *Oedogonium*) to the surface of the pond. The mat in 1949 was restricted in thickness to a surface layer. Except for occasional patches of *Oscillatoria,* filamentous algae were not observed on the bottom in depths exceeding 5 feet. Patches of *Oscillatoria* were observed on the surface or on the under side of the floating algal mat at various times during the year; excessive occurrence of these patches appeared to be associated with hot weather.

According to Tiffany and Transeau (1927), the genus *Oedogonium* reaches sexual maturity largely in spring and summer. They reported two major crests (May, June) and a minor crest (October) of fruiting. Observations of fruiting *Oedogonium* in the algal mat were made in the farm pond studied. A "small" form was observed in the fruting condition on June 4, 11, 18, 19, 24, July 1, 8, 29, August 12, 1948 and May 5, 1949; a "large" form, on June 19, 24 and November 4, 1948. In no observation was fruiting abundant.

Spirogyra appeared in July, 1948 and persisted into the winter. *Spirogyra* was observed conjugating on August 5, 1948 and October 14, 1948.

Hall (1947) made observations on algae of this farm pond during the summer of 1947. He reports that *Oedogonium* was the only filamentous algae observed in his initial collection on June 19, 1947 and that in a period of one week in the middle of July this form disappeared entirely. This disappearance was probably nothing more than the result of physical destruction of the mat by excessive precipitation occurring on July 14–15; during this period 3.87 inches of rainfall were recorded at The Ohio State University Weather Station. Hall (1947) also reported that by the latter part of July the dominant from of algae was *Euglena.* This was replaced by a species of *Oedogonium.* His description indicates that it was the "large" form observed by the writer. At no time during 1947 was a mat present as extensive as that observed during 1948 and 1949.

Diatoms were observed throughout the year but they varied considerably as to number and location. Diatoms were very rare in the surface layers of the algal mat. The number observed on the lower surface of the floating algal mat showed extreme variation; there they occurred in the greatest numbers during spring and fall. During the winter, fragments of the mat contained large numbers of diatoms. Fritsch and Rich (1913), studying a pond in the British Isles, reported diatoms as being abundant chiefly during the winter months. In "decaying" portions of the algal mat (generally in shallow water at the inlet and end along the margin of the pond) diatoms occurred commonly throughout the period studied. These "decaying" portions also contained the greatest numbers of motile forms of all types. Motile forms were generally rare in "healthy" portions of the mat, an area of no detectable free carbon dioxide. Such observations further substantiate the inference that free carbon dioxide may be a limiting factor in relation to phytoplankton production.

According to Platt (1915) working on "blanket algae" of freshwater pools, four predominate diatoms occurred: *Navicula, Synedra, Gomphonema,* and *Cocconema* (*Cymbella*). In the algal mat of the farm pond reported on in this paper, *Navicula, Synedra, Gomphonema, Cocconeis* and *Rhopalodia* were the dominant diatoms. The naviculoid forms (*Navicula* and *Synedra*) occurred throughout the year. *Gomphonema* was predominantly a spring and early summer form. *Cocconeis* was observed primarily epiphytic on "decaying" *Cladophora*. The lack of observations of *Cocconeis* during the spring of 1949 probably was the result of the relatively small amount of *Cladophora* present. This inference is substantiated by Fritsch and Rich (1913) who state, "With the absence of *Cladophora* there is lost one of the most suitable substrata for growth of certain epiphytes, this may partly account for the non-occurrence of such forms as *Cocconeis*." *Rhopalodia* was observed only from August 26, 1948 through January 6, 1949. Its period of greatest abundance was during September.

Scenedesmus, *Cosmarium* and *Euglena*, as also observed by Hall (1947), occurred primarily during summer months.

Enormous numbers of *Simocephalous* were observed on the edge of the algal mat. *Chydorus* was the only Cladoceran observed in great numbers *in* the mat and was common during a portion of the spring of 1949. Its absence in the spring of 1948 was probably due to an oversight in neglecting to record certain organisms at the initiation of the study.

Other than algal forms the only aquatic plant observed in the pond was *Potamogeton*. It was common during 1948 in water less than three feet deep. In 1949, prior to the removal of the algal mat, it was scarce, probably as a result of the "early" rise to the surface of the algal mat, but with removal of the algal mat it became common.

In conclusion it might be said that, although the method of sampling offers opportunity for improvement, there appears to be definite time relationships involved in appearance of certain organisms. Data concerning types and numbers of organisms in the algal mat appear to bear very little relationship to similar data on net plankton.

Effects of removal of the algal mat. It should be recalled that natural conditions of the pond were disturbed with removal of the algal mat and that any subsequent observations cannot be considered "typical" for this pond. Previous discussions, unless otherwise stated, referred only to observations made prior to this period of algal mat removal.

Limited observations indicate that there was an increase in the amount of net plankton and a decrease in the amount of dissolved oxygen after removal of the algal mat and subsequent stirring of the bottom mud (fig. 11). The mat was partly removed on June 22, 1949 and was, for all practical purposes, completely removed on June 23, 1949. Removal of the mat, by physical means, was followed by a rapid growth and an apparently increased photosynthetic rate by filamentous algae, as indicated by patches of filamentous green algae present on the bottom which rose to the surface and in a short time formed a fairly extensive mat. The algal mat was again removed on July 2, 1949 after chemical determinations had been made.

Miscellaneous observations. In addition to the primary investigation, miscellaneous observations were made upon vertebrates and invertebrates occurring within and around the pond.

The fishes and amphibians observed consisted of largemouth black bass (*Micropterus salmoides*), bluegills (*Lepomis microchirus*) and leopard frogs (*Rana pipiens*).

The turbid condition of water during the spring of 1948 and 1949 prevented accurate observations on the initiation of spawning. Bluegills were first observed spawning on May 28, 1948, and May 6, 1949. At no time were bass observed to be

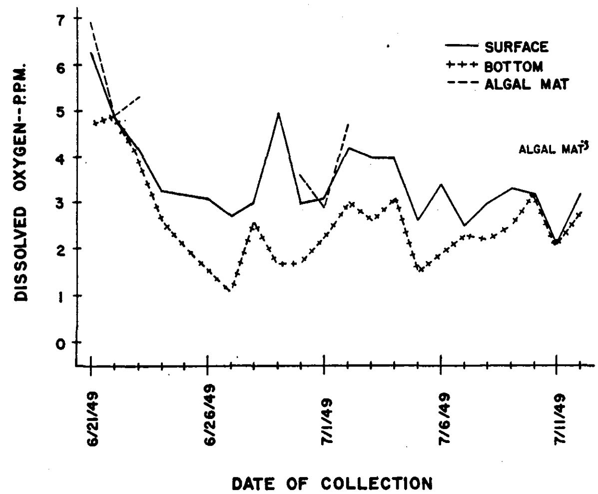

FIGURE 11. Dissolved oxygen values during and following removal of algal mat.

spawning. The absence of observations of bass fingerlings in the summer of 1948 indicates that bass did not spawn that year (the pond was stocked during the fall of 1947 with fingerling bass). Bass fry and fingerlings were observed during the summer of 1949. Extreme differences in the size of young bluegills and bass were quite evident during the latter part of June, 1949; bass were nearly of fingerling size while bluegills were much smaller. Such an extreme difference in size indicates that bass were spawning earlier than bluegills. The algal mat prevented observations on the cessation of spawning; the latest spawning observation for bluegills was on August 12, 1948.

On August 30, 1949, the pond was drained and enormous numbers of small bluegills and black bass were obtained. Eighty-nine bluegills over 5 inches long and 18 largemouth black bass over 11 inches in length were obtained. As far as can be determined these 18 bass plus three removed in the spring approximately equal the number of fingerlings stocked during the fall of 1947. Adult bass showed a growth of about two inches from the first week of April 1949 until August 30, 1949.

Frogs or tadpoles were common at certain periods. Adult frogs were numerous on April 16, 1948 and tadpoles were abundant by May 21, 1948. Frogs were first observed on March 20, 1949, but by April 1, 1949 they had disappeared, probably as a result of a cold period. They were again observed in large numbers on April 22, 1949, followed by tadpoles on May 6, 1949.

There were no observations of adult frogs by the time tadpoles were observed. Observations indicate that the algal mat probably prevents bass from catching the tadpoles and young frogs. Following the physical removal of the mat, during the summer of 1949, extreme surface agitation in the shallows near concentrations of tadpoles indicated that fish were feeding heavily upon them.

Snails were common in the pond and were very conspicuous during the summer of both years.

The pond in the spring of 1946 and 1948 contained large numbers of similar aquatic insects. Collections made on June 24, 1946 by Julian L. Dusi contained: Corixidae, Dytiscidae, Gerridae, Heliplidae, Hydrophilidae, and Notonectidae.

In the spring of 1949 the pond was almost completely lacking in insects. On February 24, 1949 enormous numbers of midges were observed emerging. They were present until March 3, 1949 after which date, probably as a result of cold weather, none were observed. Dragon flies and damsel flies were periodically common during both years of study. The damsel flies preceded the dragon flies in time of appearance. Large numbers of dragon flies were observed on June 24, 1948 and June 10, 1949, occurring after a period of almost complete absence.

Game birds and animals on the farm pond area consisted of blue-winged teal, lesser scaup, ring-necked pheasant, woodcock, dove, rabbit and raccoon.

FISH MORTALITY IN THE POND

On September 1, 1947 fish mortality occurred and a total of 168 bluegills and 11 black bass were floating on the surface. As measured by Julian L. Dusi, the 11 bass averaged 24.3 cm, and 124 of the bluegills averaged 14.7 cm in length; the remainder of the bluegills were about 4 cm long. These fish were stocked as fingerlings and fry during the fall of 1946. Records of summer fish mortality are common in the literature but generally data on dissolved oxygen or free carbon dioxide does not accompany such reports. Dissolved oxygen determinations in connection with summer fish mortality have been reported by Smith and Swingle (1938) as 0.1 ppm (2 P.M.), 3.4 ppm (9 P.M.) and 0.8 ppm (4 A.M.); Tomlinson (1935) reported barely a trace of dissolved oxygen. Smith and Swingle (1938) reported mortality occurring after excessive fertilization. Tomlinson's observations were made on a 125–150 acre "weed bottom" lake a few days after the occurrence of severe rains and an abrupt change in temperature. Roach and Wickliff (1934) also reported mortality, occurring in the presence of vegetation, after a severe wind and rain storm.

Mortality observed in the farm pond studied occurred during or shortly after a severe rain storm; this storm was accompanied by thunder and lightning. Whether or not the fish died as a result of the pond being struck by lightning or other factors is not known. An analysis of the weather conditions prior to the mortality offers a possible explanation of this summer kill.

The algal mat, as previously discussed, did not exist, although filamentous algal were present along the edges of the pond. Observations indicate that green *Oedogonium* if present on the bottom of the pond rises to the surface during periods of warm weather. Providing that these observations are applicable to other filamentous green algae, it is doubtful that filamentous green algal were present on the bottom of the pond at the time of the fish kill as the month of August was the warmest in 65 years and no free floating algae was observed. Surface water temperatures determined by Hintz and Reynolds during August were in the low thirties (° C).

A relatively high summer water level, one foot below the overflow, existed and probably was a result of the lack of an algal mat, which increases the evaporating surface of the pond, and the presence of heavy precipitation in June followed by the lowest average temperature during July in Ohio since 1891.

The above conditions appear to be conducive to the development of "low" dissolved oxygen values as absence of filamentous green algae indicates little oxygen produced as a result of photosynthesis; high water temperatures result in greater oxygen consumption by fish and an increased threshold of survivability; warm weather is probably conducive to greater bacterial action with the subsequent reduction of oxygen; dispersal of organic material from the bottom as a result of heavy precipitation may be conducive to increased bacterial action or, as suggested by Tomlinson (1935), the washing of bacteria into a pond may indirectly be the cause of oxygen depletion.

The mixing of bottom and surface waters, as a result of heavy winds and cold rains flowing to the bottom with subsequent equalization of small amounts of dissolved oxygen throughout the pond, might possibly have resulted in dissolved oxygen being below the critical amount required for fish survival. It is conceivable that such a condition could have occurred on July 29, 1948 in the pond, as the dissolved oxygen content on the bottom was 0.1 ppm and the surface water had the lowest amount detected during the undisturbed study (April 16, 1948 to June 21, 1949). Bluegills were observed, with the exception of early morning and evening, for the first time in the surface water.

SUMMARY

1. Selected biological, physical, and chemical conditions of an Ohio farm pond were studied at weekly intervals over a sixteen month period.
2. Photosynthesis, strong winds, and heavy rains have an effect upon the dissolved oxygen content of a pond.
3. During portions of the winter relatively large amounts of dissolved oxygen occurred concurrently with "blooms" of *Chlamydomonas*.
4. An algal surface cover has a profound influence upon various physical, chemical, and biological conditions.
5. Supersaturation of dissolved oxygen occurred commonly.
6. Numerically, zooplankters were the dominant plankters during spring; phytoplankton were dominant during winter.
7. In general, rotifers were the most commonly observed plankters.
8. The kind and number of organisms in the algal surface cover had little relationship to the kind and number of net plankters.
9. Removal of the algal surface cover had an effect on certain biological, physical, and chemical conditions.
10. In general, there was a reoccurrence in 1949 of similar biological, physical, and chemical conditions observed in 1948.
11. Daily and seasonal variability occurred in various biological, physical, and chemical conditions.
12. The temperature of the surface and bottom water is influenced by air temperature.
13. In general, an extensive algal mat was accompanied by maximum light transmission.
14. An algal surface cover apparently has an effect of increasing the amount of evaporation from a pond surface.
15. A discussion of summer fish mortality is presented.

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The data collected during this study are tabulated in the following: Schultz, Vincent, 1949—A limnological study of a farm pond. Dissertation, The Ohio State University, Columbus, Ohio.

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